

Performance analysis of advanced hybrid GAX cycles: HGAX

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Received 3 July 2003; received in revised form 24 October 2003; accepted 24 October 2003

Abstract

The objectives of this paper are to develop advanced hybrid GAX cycles (HGAX) using $\text{NH}_3\text{-H}_2\text{O}$ by combining absorption and vapor compression cycles, and to perform parametric analysis of system pressures and component sizes for performance enhancement. Four different HGAX cycles are developed—Type A (Performance improvement), Type B (Low temperature applications) Type C (Reduction of desorption temperature) and Type D (Hot water temperature applications). A compressor is placed between the evaporator and the absorber in Type A and Type B, and placed between the desorber and the condenser in Type C and Type D. It is found that the COP can be improved by 24% compared with the standard GAX cycle (in Type A) and the evaporation temperature of as low as $-80\text{ }^\circ\text{C}$ can be obtained from the HGAX cycle (Type B). In Type C, the maximum desorption temperature can be reduced down to $164\text{ }^\circ\text{C}$. Therefore, the corrosion problem, which becomes severe at higher temperature $200\text{ }^\circ\text{C}$, can be completely removed. The maximum desorption temperature for the standard GAX cycle ranges $190\text{--}200\text{ }^\circ\text{C}$. In Type D, the hot water temperature of as high as $106\text{ }^\circ\text{C}$ could be obtained. Therefore, Type D can be applied for space heating and panel or floor heating applications.

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Keywords: Absorption system; Ammonia–water; Mechanical vapour compression; Modelling; Performance

Recherche avancée : analyse de la performance des cycles hybrides GAX (HGAX)

Mots clés : Système à absorption ; Ammoniac–eau ; Compression mécanique de vapeur ; Modélisation ; Performance

1. Introduction

The internal heat exchange due to the temperature glide of $\text{NH}_3\text{-H}_2\text{O}$ mixture provides the fundamental basis for the Generator Absorber heat eXchange (GAX) cycle [1]. The GAX cycle essentially appears to be a

single stage configuration. However, it provides a higher coefficient of performance (COP) than any other single effect cycle due to the temperature overlap between the generator and the absorber. Fig. 1 shows the fundamental concept of the GAX cycle–temperature overlap. The dotted lines represent the single stage cycle of the low pressure side while the solid lines represent the GAX cycle. As the absorber pressure increases, the corresponding absorber temperature increases in the ammonia–water absorption cycles. The temperature ranges partially overlap between the absorber and

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Nomenclature

COP	Coefficient of performance
GAXA	GAX absorber
GAXD	GAX desorber
GFD	Gas fired desorber
HCA	Hydronically cooled absorber
SCA	Solution cooled absorber
SHD	Solution heated desorber
P	Pressure (kPa)
Q	Heat transfer rate (kW)
T	Temperature (°C)
x	concentration
UA	Overall conductance (kW/K)
W	Work (kJ)

Subscript

a	absorber
c	cooling, condenser
comp	compressor
d	desorber
e	evaporator
gaxa	GAX absorber
h	heating
h,t	heating total
out	outlet

generator as the absorber exit temperature increases. The “overlapped” heat is internally transferred from the absorber to the generator leading to a higher COP. This overlapped heat is an attractive characteristic of the GAX cycle using $\text{NH}_3\text{-H}_2\text{O}$, which can not be realized in $\text{LiBr-H}_2\text{O}$ absorption systems. The term “generator” is replaced by “desorber” from now since the term “desorber” is academically proper for a binary mixture such as $\text{NH}_3\text{-H}_2\text{O}$. Many papers have been found on the standard GAX cycle [2–7]. Recently, the GAX cycle is adopted in many applications such as space heating, space cooling and refrigeration. It can be also combined with a vapor compression process to obtain a higher COP or to obtain a lower refrigeration temperature. This cycle was called GAX hybrid cycle [8]. Kang et al. [9] developed an advanced GAX cycle for utilization of waste heat which was called WGAX cycle. They reported that the generator outlet temperature could be reduced to 172 °C with a higher COP of the WGAX cycle than that of the standard GAX (SGAX) cycle. They presented that the corrosion problem in the standard GAX cycle at higher T_d than 200 °C could be solved by adopting the WGAX cycles with a comparable COP. Kang et al. [10] developed an environmentally friendly GAX cycle using $\text{NH}_3\text{-H}_2\text{O}$ for panel heating applications which was called the PGAX cycle. For space heating applications, 45 °C of coolant is high

enough since room temperature is typically about 26 °C. However, 65 °C of coolant is required for panel heating in which the coolant flows through pipes under the wall or floor. The PGAX cycle can be operated in three different modes with just one hardware—cooling, space heating and panel heating applications.

The objectives of this paper are to develop the advanced GAX cycles named Hybrid GAX (HGAX) cycles, and to study the effect of key parameters on the cycle performance and the evaporation temperature. Four different advanced HGAX cycles are developed—Type A (Performance improvement), Type B (Low temperature applications) Type C (Reduction of desorption temperature) and Type D (Hot water temperature applications). A compressor is placed between the evaporator and the absorber in Type A and Type B, and placed between the desorber and the condenser in Type C and Type D. In Type A and Type B, the evaporator pressure and the absorber pressure are controlled according to its application purpose. In Type C and Type D, the condenser pressure and the generator pressure are controlled according to its application purpose.

2. Description of HGAX cycle

Fig. 2 shows the HGAX cycles—Type A and Type B. In the HGAX cycles, the compressor is placed between the evaporator and the absorber. The goals of Type A and Type B are to obtain a high cycle COP (performance improvement) and to provide a low evaporation temperature (low temperature application), respectively. In Type A, the evaporator pressure is same as the pressure in the standard GAX cycle while the absorber pressure becomes higher than the evaporator pressure. The cycle of Type A cycle provides a wide temperature overlap between the absorber and the desorber leading to a high cycle performance. In Type B, the absorber pressure is same as the pressure in the standard GAX cycle while the evaporator pressure becomes lower than the absorber pressure leading to a low evaporation temperature.

Fig. 3 shows the HGAX cycles—Type C and Type D. In the HGAX cycles, the compressor is placed between the condenser and the desorber. The goals of Type C and Type D are to reduce the desorption temperature (reduction of desorption temperature) and to obtain a high hot water temperature (hot water temperature applications), respectively. In Type C, the condenser pressure is same as the pressure in the standard GAX cycle while the desorber pressure becomes lower than the condenser pressure. The cycle of Type C provides a low desorption temperature and therefore the corrosion problem due to the high solution temperature in the desorber can be removed. In Type D, the desorber pressure is same as the pressure in the standard GAX

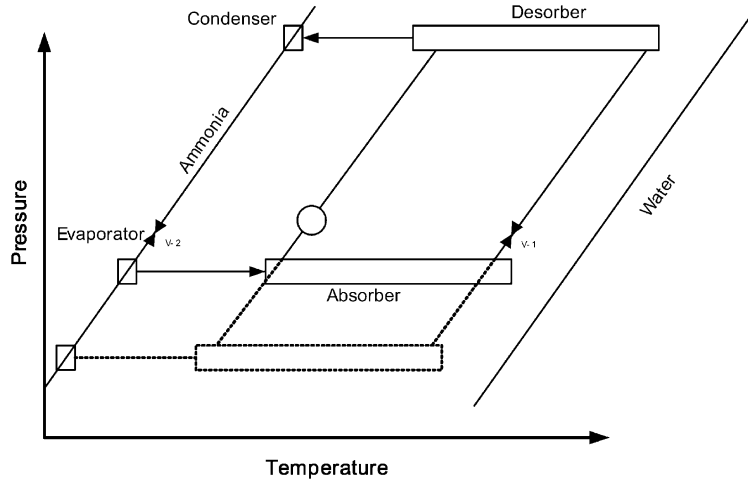


Fig. 1. Concept of the GAX cycle.

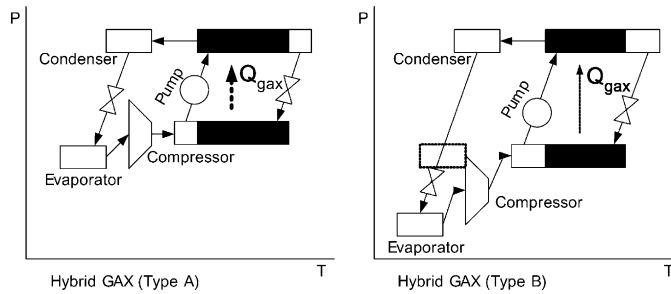


Fig. 2. Schematic diagram of the HGAX cycle (Type A and Type B).

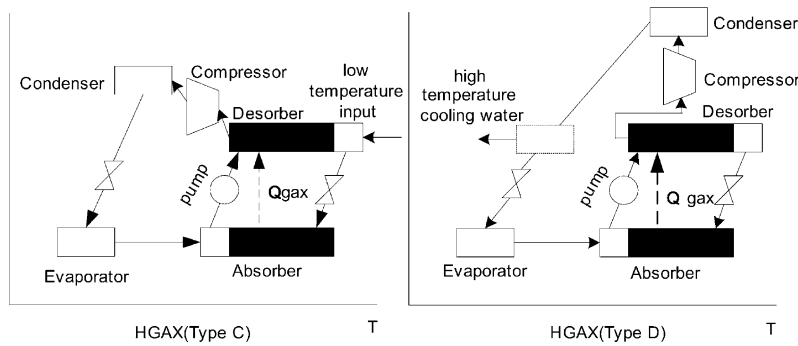


Fig. 3. Schematic diagram of the HGAX cycle (Type C and Type D).

cycle while the condenser pressure becomes higher than the desorber pressure providing a hot water temperature of as high as 100 °C. In the HGAX cycle, the hot water flows into the absorber and the condenser in series in Type D. The outlet temperature of the hot water from the absorber is about 47 °C. Some of hot water at 47 °C can be applied for space heating, and the rest flows into the condenser leaving out with the outlet temperature of

about 100 °C, which can be utilized for panel or floor heating applications.

3. Modeling approach

ABSIM (Absorption SIMulation) is used to model the HGAX cycles studied in the present paper. The

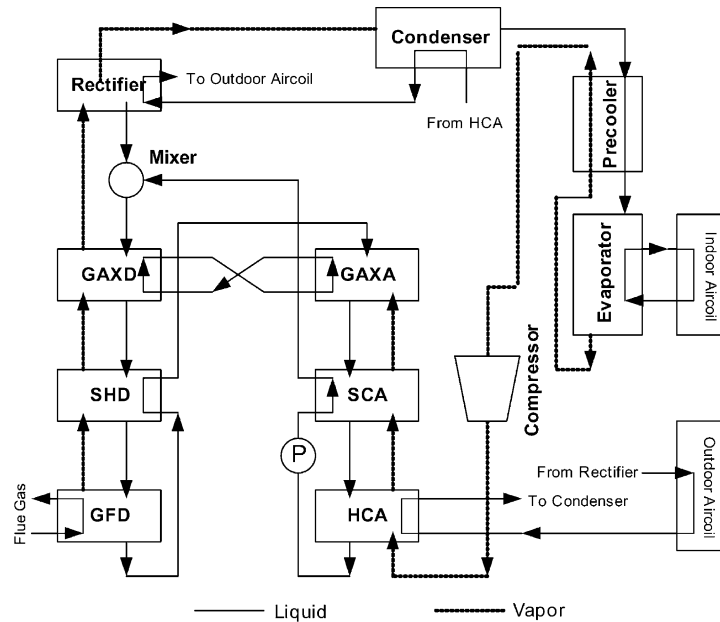


Fig. 4. Cycle diagram of the HGAX, Type A and B.

ABSIM was developed by Grossman and Wilk [11]. The ABSIM is a steady state, modular type program for simulation of absorption systems. This modular type code is based on unit subroutines containing governing equations and property subroutines containing thermodynamic properties of the working fluids. In modeling the HGAX cycles using the ABSIM, it is required to specify initial inputs for UAs of each component and thermal conditions for all state points. All the initial inputs are recalculated by checking species, mass, energy and heat transfer balances for each component. Therefore, a judicious choice of the initial inputs is required to obtain a converged set of thermal conditions. In the present cycle modeling, UA of each component is specified for parametric analysis of the pressure variation.

Fig. 4 shows the schematic diagram of the HGAX cycle using ammonia–water solution pair. The HGAX cycle consists of the following components—hydraulic cooled absorber (HCA), solution cooled absorber (SCA), GAX absorber (GAXA), gas fired desorber (GFD), solution heated desorber (SHD), GAX desorber (GAXD), rectifier, condenser, evaporator, pre cooler, air coils and compressor. In Fig. 4, solid and dashed lines represent liquid and vapor flows, respectively. Starting from desorber columns, concentrated ammonia (strong) solution enters the GAXD from the mixer while dilute (weak) solution exits at the bottom of the GFD. The term “strong solution” represents a solution that is strong with refrigerant (NH_3) while “weak solution” represents a solution that is weak with refrigerant. The weak solution is hot enough to desorb the refrigerant in the SHD, so that the weak solution is cooled in annulus

side of the SHD. The weak solution leaving the SHD enters the top of the GAXA. The vapor from the GFD is combined with the vapor from SHD and GAXD, and enters the rectifier. The purified vapor from the rectifier is then sent to the condenser while the reflux (condensate) from the rectifier flows back to the GAXD. The liquid from the condenser passes through one side of the pre cooler. The pressure of the subcooled liquid from the pre cooler is then reduced through a throttling valve. The liquid is evaporated at the low pressure of the evaporator. After passing through the other side of the pre cooler, the vapor from the evaporator enters the compressor to raise the absorber pressure. The pressurized refrigerant vapor is sent back to the bottom of the HCA, where the vapor flows counter-current to the liquid. All vapor is absorbed through HCA, SCA and GAXA. The weak solution at the top of the GAXA absorbs ammonia vapor, and exits the HCA as a strong solution. The strong solution flows into a pump, enters the SCA, and is sent back to the top of the GAXD. An external hydraulic circuit recovers heat from the GAXA to the GAXD to increase the cycle COP.

4. Results and discussion

The present study focuses on the effect of pressure variation of each component on the system performance, evaporation temperature, desorption temperature and hot water temperature depending on its application areas. Thermal input data and base line UAs of each component are summarized in Table 1.

Table 1
Base line thermal conditions for each cycle

Cycle	Type A	Type B	Type C	Type D
Thermal conditions	Pd: 1900 Pc: 1900 Pa: 1800	Pd: 1900 Pc: 1900 Pa: 460	Pd: 860 Pc: 1500 Pa: 460	Pd: 1500 Pc: 3450 Pa: 460
P (kPa)	Pe: 460	Pe: 10	Pe: 460	Pe: 460
T (°C)	Te: 1.6	Te: -72.0	Th: 168.0	Tout: 95.5
UA (kW/K)	UAd: 0.06 UAGAXA: 0.6 UAc: 0.5 UAe: 1.4	UAd: 0.11 UAGAXA: 0.6 UAc: 0.5 UAe: 1.4	UAd: 0.06 UAGAXA: 0.6 UAc: 0.5 UAe: 1.5	UAd: 0.11 UAGAXA: 0.6 UAc: 1.0 UAe: 1.5

Considering the compressor work in the HGAX cycle, the ideal COP is defined as follows;

$$COP_c = \frac{Q_c}{Q_d + Q_{comp}} \tag{1}$$

$$COP_h = \frac{Q_c}{Q_d + Q_{comp}} \tag{2}$$

and

$$COP_{h,t} = \frac{Q_c + Q_{HCA}}{Q_d + Q_{comp}} \tag{3}$$

where Q_{comp} is heat transfer rate equivalent to the compressor work (isentropic efficiency of 1.0), which is generally less than 15% of total heat input to the HGAX cycle.

Fig. 5 shows the COP_c variation as a function of the absorber pressure in Type A. The pressures of desorber and evaporator are kept constant at 1900 and 460 kPa, respectively. It is found that the COP_c increases with increasing the absorber pressure. This implies that the GAX effect (internal heat recovery by temperature overlap between the absorber and the desorber) overcomes the compression work required to operate the compressor. It is found that the COP_c in the HGAX Type A increases as high as 1.24 by controlling the absorber pressure, which is about 24% higher than the COP_c in the standard GAX cycle with the same thermal conditions.

Fig. 6 shows the evaporation temperature and the COP_c versus the evaporator pressure in Type B. The pressures of desorber and absorber are kept constant at 1900 and 460 kPa, respectively. The evaporation temperature and the COP_c decrease with decreasing the evaporator pressure. It is found that the evaporation of -80 °C can be obtained from the HGAX Type B with the COP_c of 0.3. The evaporation temperature of -50 °C is also obtained with the COP_c of 0.58, which is much

higher than the conventional vapor compression cycle for low temperature applications. The COP_c decreases due to the increasing compressor work and the decreasing latent heat of the refrigerant at a low evaporator pressure.

Fig. 7 shows the COP_c and the highest desorption temperature, T_h (outlet temperature from the desorber) versus the desorber pressure in Type C. The pressures of condenser and evaporator are kept constant at

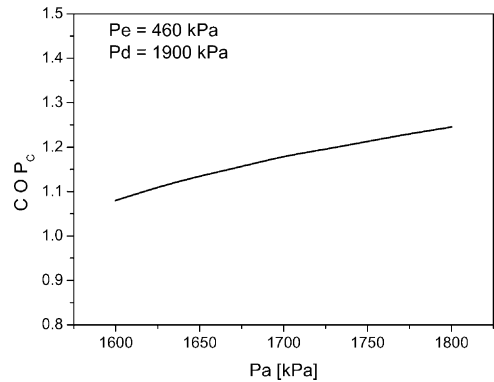


Fig. 5. COP_c versus absorber pressure in Type A.

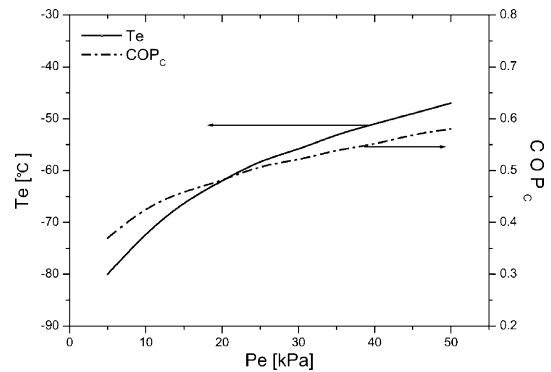


Fig. 6. T_e and COP_c versus evaporator pressure in Type B.

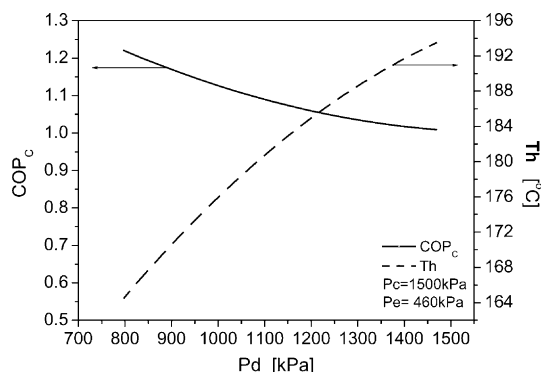


Fig. 7. COP_c versus desorber pressure in Type C.

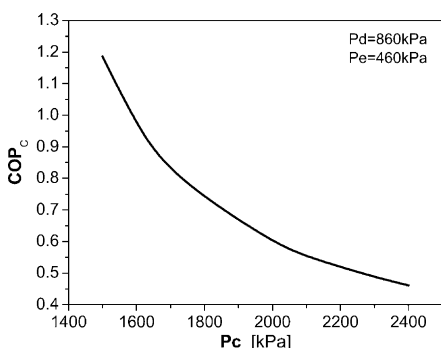


Fig. 8. COP_c versus condenser pressure in Type C.

1500 and 460 kPa, respectively. As the desorber pressure decreases, the COP_c increases and the T_h decreases. The highest desorption temperature decreases as low as 168 °C, and therefore the corrosion problem at a higher temperature than 200 °C can be completely removed by adopting the HGAX-Type C. At the same time, the COP_c is improved by the increasing GAX effect which recovers the internal heat from the GAXA to the GAXD. Even though the compression work increases with decreasing the desorber pressure, the cooling capacity Q_e at the evaporator increases more because the desorption amount of the refrigerant at the desorber increases significantly. It is also found that the COP_c in the HGAX Type C increases as high as 1.19 by controlling the desorber pressure, which is about 19% higher than the COP_c in the standard GAX cycle with the same thermal conditions.

Fig. 8 shows the COP_c variation as a function of the condenser pressure in Type C. The pressures of desorber and evaporator are kept constant at 860 and 460 kPa, respectively. The COP_c decreases with increasing the condenser pressure. This is because the Q_d and Q_e are

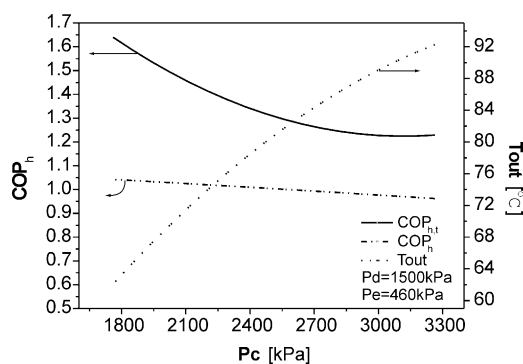


Fig. 9. COP_h and T_{out} versus condenser pressure in Type D.

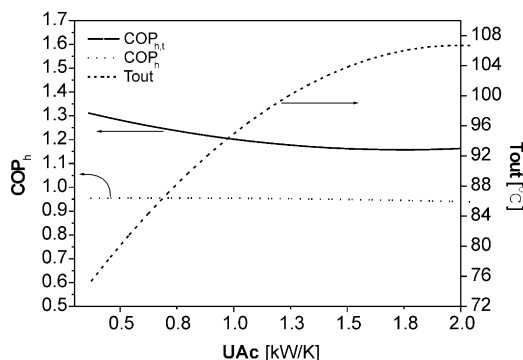


Fig. 10. COP_h and T_{out} versus UA_c .

almost kept constant while the compression work increases significantly as the condenser pressure increases.

Fig. 9 shows the COP_h and the outlet temperature of the hot water versus the condenser pressure in Type D. The pressures of desorber and evaporator are kept constant at 1500 and 460 kPa, respectively. As the condenser pressure increases, the outlet temperature of the hot water increases as high as 92 °C while the COP_h decreases as low as 0.95 due to the increasing compression work. As the condenser pressure increases, the $COP_{h,t}$ decreases significantly from 1.65 to 1.25 while the COP_h does not (1.05–0.95). It is because Q_{HCA} , which is included in the $COP_{h,t}$ decreases significantly up to the condenser pressure of 2700 kPa.

Fig. 10 shows the COP_h and the outlet temperature of the hot water versus UA of the condenser in Type D. The pressures of condenser, desorber and evaporator are kept constant at 3450, 1500 and 460 kPa, respectively. As UA of the condenser increases, the heat capacity of the condenser Q_c also increases leading to a high outlet temperature of the hot water. The maximum hot water temperature of 106 °C is obtained from the HGAX-Type D developed in the present study.

5. Conclusions

This study developed four different advanced HGAX cycles by controlling the pressures of evaporator, absorber, condenser and desorber depending on its applications—performance improvement, low temperature applications, reduction of desorption temperature and hot water temperature applications. The following conclusions are drawn from the present study.

1. It is found that the COP_c in the HGAX-Type A increases as high as 1.24 by controlling the absorber pressure, which is about 24% higher than the COP_c in the standard GAX cycle with the same thermal conditions.
2. In HGAX-Type B, the evaporation temperature and the COP_c decrease with decreasing the evaporator pressure. It is found that the evaporation of -50 to -80 °C can be obtained from the HGAX-Type B with the COP_c of 0.58–0.3.
3. The highest desorption temperature decreases as low as 168 °C, and therefore the corrosion problem can be completely removed by adopting the HGAX-Type C. It is also found that the COP_c in the HGAX-Type C increases as high as 1.19 by controlling the desorber pressure, which is about 19% higher than the COP_c in the standard GAX cycle with the same thermal conditions.
4. In HGAX-Type D, the maximum hot water temperature of 106 °C is obtained. Some of hot water at 47 °C (at the outlet of the absorber) can be applied for space heating, and the rest with the outlet temperature of 106 °C can be utilized for panel or floor heating application.

Acknowledgements

This paper was performed for the Carbon Dioxide Reduction & Sequestration Center, one of 21st Century

Frontier R&D Programs funded by the Ministry of Science and Technology of Korea.

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